

INFECTION OF YOUNG DOUGLAS-FIRS BY DWARF MISTLETOE IN THE SOUTHWEST

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ABSTRACT.—Studies in several areas in Arizona and New Mexico show that dwarf mistletoe (*Arceuthobium douglasii*) is rare in young Douglas-firs growing under infected overstories. Less than 5% of the Douglas-firs under 26 years old and less than 6% of those under 1.4 m tall were infected in 77 mistletoe-infested stands. Both percent infection and mean dwarf mistletoe rating of young Douglas-firs increased as tree age, height, and stand dwarf mistletoe ratings increased.

Douglas-fir dwarf mistletoe (*Arceuthobium douglasii* Engelm.) is the most prevalent and damaging disease agent in southwestern mixed-conifer forests (Andrews and Daniels 1960, Hawksworth and Wiens 1972, Jones 1974). This parasitic flowering plant occurs throughout the range of its principal host, Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), in the Southwest. Andrews and Daniels (1960) estimated that approximately 50% of the Southwest's Douglas-fir type was infested by dwarf mistletoe.

Douglas-fir regeneration is a frequent component of the understory of southwestern mixed-conifer stands (Moir and Ludwig 1979, Gottfried and Embry 1977, Fitzhugh et al. 1987). When overstories are infested with dwarf mistletoe, spread to young and advance regeneration perpetuates the infestation over time. Therefore, management of mixed-conifer forests should attempt to minimize the infection of new and established regeneration from already infested overstories (Jones 1974, Gottfried and Embry 1977).

Mathiasen (1986) summarized previous research on this problem and the factors that influence dwarf mistletoe infection; he also provided some preliminary information on infection of young Douglas-firs and spruces in the Southwest. He found that little infection of Douglas-fir occurs before saplings are 26 years old. Only 6% of the Douglas-firs he sampled that were less than 26 years old were infected, whereas infection of older Douglas-fir reproduction averaged 83%. Mathiasen

(1986) also related infection of Douglas-firs less than 26 years old to three factors affecting infection of young trees listed by Wicker (1967). These included exposure time, overstory inoculum levels, and sapling density.

During a study designed to collect growth data for the development of a regeneration model for southwestern mixed-conifer stands, additional data on the infection of young Douglas-firs were collected from 13 mistletoe-infested stands in the White Mountains, Arizona. These data were combined with the original data collected by Mathiasen (1986), and the results are reported here. In addition, the entire data set was summarized using the heights of sampled Douglas-firs because previous investigators have suggested that height may be a critical factor influencing infection of young trees by dwarf mistletoes (Graham 1960, Hawksworth 1961, Childs 1963, Wicker and Shaw 1967, Scharpf 1969).

METHODS

During 1980–81 Douglas-fir regeneration was sampled in 64 mistletoe-infested mixed-conifer stands in four national forests in Arizona and New Mexico. A total of 364 Douglas-fir saplings were sampled for total age, height, and height to live crown. In addition, each Douglas-fir was examined for dwarf mistletoe infection and assigned a dwarf mistletoe rating (DMR) using the 6-class system (Hawksworth 1977). This rating system divides the live crown of a tree into thirds, and each third is

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rated separately as: 0, no mistletoe infection; 1, less than 50% of live branches infected; 2, more than 50% of live branches infected. The ratings for each third are totaled to obtain the DMR for a tree. Mean stand DMR and mean sapling DMR are calculated by adding the DMRs for all live overstory trees or saplings and dividing by the total number of live trees or saplings, respectively. Infection intensity is defined here as the mean DMR of the overstory or saplings in a stand.

Overstory data collected for the 1980–81 stands were from rectangular plots ranging from 0.04 to 0.36 ha. For each live tree over 1.4 m in height the species, diameter at breast height (dbh) to the nearest 2.54 cm, DMR, and crown class (dominant, co-dominant, intermediate, or suppressed) were recorded. These data provided information on overstory dwarf mistletoe infection intensity, species composition, and stand structure.

In 1988 an additional 334 Douglas-fir saplings were sampled in 13 mistletoe-infested, mixed-conifer stands in the White Mountains, Arizona. Data were collected as in 1980–81. Overstory data collected were the same as in 1980–81 but 0.04-ha circular plots were used.

Stand dwarf mistletoe ratings were calculated using all live Douglas-firs greater than 2.54 cm dbh for 1980–81 plots and greater than 5.08 cm dbh for 1988 plots. Sapling crown ratios were calculated by subtracting height to live crown from total height and then dividing by total height. Percent infection and mean DMR for saplings were calculated by five-year age classes and .3-m height classes for each of three stand DMR classes (0.1–1.5, 1.6–3.0, and greater than 3.0). Sapling densities were determined for the number of Douglas-fir saplings in 0.04-ha circular subplots nested in the center of larger plots in each stand.

RESULTS

Both the number of infected saplings (percent infection) and infection intensity (mean DMR) increased as total age, total height, and stand DMR increased (Tables 1 and 2). No mistletoe infection was found on saplings under 21 years old in stands with a stand DMR less than 3.0, and only five saplings under 21 years old were infected in stands with a stand DMR greater than 3.0 (Table 1). The five

infected saplings represent less than 4% of saplings under 21 years old sampled. Infection of saplings less than 16 years old was only 2% in stands with a stand DMR greater than 3.0. Also, very little infection of saplings less than 26 years old was found (Table 1). Only 10% of saplings 21–25 years old were infected, and all were in moderately infested (stand DMR 1.6–3.0) or severely infested stands (stand DMR greater than 3.0).

Infection of 26–30-year-old saplings increased to 30% in lightly infested stands (stand DMR 0.1–1.5) and to over 65% in both moderately and severely infested stands (Table 1). Generally, infection continued to increase as sapling age increased (Table 1).

A total of 14 infected saplings under 26 years old were sampled. These saplings were in severely infested stands, were over 1.4 m in height, had high crown ratios (greater than 0.70), or were in stands with over 740 saplings per ha. Many of these 14 saplings had more than one of the above factors contributing to their infection potential.

Percent infection and mean DMR for saplings demonstrated the same pattern for height classes as for age classes (Tables 1, 2). Little infection (10% or less) was found in saplings less than 1.4 m in height, except in the most severely infested stands, where we found 27% infection in saplings 1.09–1.4 m tall. However, saplings over 1.4 m in height had much higher infection levels (percent infection) and intensities (mean DMR) than smaller saplings (Table 2).

DISCUSSION

Wicker (1967), Wicker and Shaw (1967), and Mathiasen (1986) discussed several of the factors influencing the infection of young trees by dwarf mistletoes, including duration of exposure to inoculum, amount of inoculum, target area, density of regeneration, and removal of seeds by wind, snow, and other environmental factors. Infection of susceptible young trees is largely influenced by a complex interaction of the above factors. Mathiasen (1986) presented information on the influence of exposure duration to inoculum (as expressed by tree age), amount of inoculum (as expressed by stand DMR), and regeneration density (as expressed by number of saplings per ha). Additional information is reported

TABLE 1. Infection of Douglas-fir saplings by age classes and stand DMR classes.

Age class (years)	Stand DMR class											
	0.1-1.5			1.6-3.0			> 3.0			Total		
	N	% Inf ¹	Mean DMR	N	% Inf	Mean DMR	N	% Inf	Mean DMR	N	% Inf	Mean DMR
< 16	49	0	0.0	58	0	0.0	108	2	<0.1	215	1	<0.1
16-20	30	0	0.0	29	0	0.0	21	14	0.1	80	4	<0.1
21-25	15	0	0.0	43	9	<0.1	35	14	0.1	93	10	<0.1
26-30	27	30	0.3	38	79	0.8	35	69	0.7	100	62	0.6
31-35	8	25	0.3	39	80	1.1	41	88	0.9	88	78	0.9
36-40	12	66	0.9	40	90	1.4	36	97	1.8	88	90	1.5
41-45	7	71	0.9	15	80	2.0	12	100	2.8	34	85	1.9
Total	148	16	0.2	262	43	0.6	288	41	0.6	698	36	0.5

¹Percent infection

TABLE 2. Infection of Douglas-fir saplings by height classes and stand DMR classes.

Height class (m)	Stand DMR class											
	0.1-1.5			1.6-3.0			> 3.0			Total		
	N	% Inf ¹	Mean DMR	N	% Inf	Mean DMR	N	% Inf	Mean DMR	N	% Inf	Mean DMR
.15-.45	23	0	0.0	20	0	0.0	45	0	0.0	88	0	0.0
.46-.76	14	0	0.0	13	0	0.0	35	3	<0.1	62	2	<0.1
.77-1.07	21	5	<0.1	33	0	0.0	31	6	0.1	85	4	<0.1
1.10-1.37	21	5	0.2	29	10	0.1	22	27	0.2	72	14	0.2
1.40-1.68	15	27	0.4	44	61	1.2	32	66	1.3	91	57	1.0
1.71-1.98	15	40	0.7	48	65	1.5	41	71	1.6	104	64	1.4
2.01-2.29	9	44	0.6	23	70	1.4	24	75	2.0	56	68	1.3
< 2.29	30	23	0.6	52	70	1.2	58	69	1.8	140	59	1.4
Total	148	16	0.2	262	43	0.6	288	41	0.6	698	36	0.5

¹Percent infection

here for these factors as well as for the influence of target area as expressed by the total height and crown ratio of young infected Douglas-firs. In most situations where infected young Douglas-firs (less than 26 years old) were found, a severely infested overstory (stand DMR greater than 3.0) was present. Infected young Douglas-firs in stands with a stand DMR less than 3.0 either had high crown ratios (greater than 0.70), were over 1.4 m tall, or were in stands with regeneration densities over 740 saplings per ha. All three factors would increase the potential for infection of young trees in dwarf mistletoe-infested stands because of greater available target area.

Because severe infection by dwarf mistletoe significantly reduces the growth of merchantable-size Douglas-firs in the Southwest and increases mortality of all size classes (Andrews and Daniels 1960, Mathiasen et al. 1990), its control is an important consideration for resource managers. Vegetation man-

agement plans that do not successfully prevent or significantly reduce the infection of Douglas-fir regeneration only serve to perpetuate mistletoe infestations. Although the total heights, crown ratios, and densities of regeneration contribute to the potential for reinfection of young understories, these factors cannot be managed on a practical basis. However, management plans that remove the most severely infected trees, followed with intermediate sanitation removals, can effectively reduce the level of dwarf mistletoe infection in stands (Hawksworth 1978), thereby reducing the potential for infection of new or advance regeneration. In addition, because Douglas-fir regeneration is not frequently infected before it reaches ages over 25 years in the Southwest, cutting cycles of 20 years or less allow managers at least two management entries for reducing the level of mistletoe in a stand before new Douglas-fir regeneration will be affected. Because little or no infection will occur until Douglas-firs are over 20 years

old in lightly infested stands, the removal of severely infected overstory trees will significantly reduce the potential for infection of new and advance Douglas-fir regeneration.

The age at which Douglas-fir regeneration becomes infected by dwarf mistletoe in the Southwest contrasts sharply with results reported for other tree species and regions. Weir (1918) found that the average age of 50 naturally infected Douglas-fir seedlings, used for assessing the effects of dwarf mistletoe on seedling growth in the Northwest, was 18 years. Hawksworth and Graham (1963) found very little infection in lodgepole pine (*Pinus contorta* Dougl. ex Loud.) reproduction under 10 years old, but infection increased markedly in older stands: 9% at age 15, 18% at age 20, and 32% at age 25. Some infection of ponderosa pine (*Pinus ponderosa* Laws.) by southwestern dwarf mistletoe (*Arceuthobium vaginatum* subsp. *cryptopodium* [Engelm.] Hawksw. & Wiens) has been found in 10-year-old seedlings (Gill and Hawksworth 1954, Hawksworth 1961). Based on these findings for pines, Johnson and Hawksworth (1985) recommended that mistletoe-infected residual trees be removed before the young stand is 10 years old. However, the results of this study indicate that for southwestern Douglas-fir the infected overstory trees could be left for up to 20 years because of the very slight chance of infection.

There is less published data for the relationship of regeneration height and dwarf mistletoe infection, but the general recommendation is that mistletoe-infected residual trees should be removed before the young stand is 0.9 m tall (Johnson and Hawksworth 1985). Graham (1960) found that dwarf mistletoe infection in Douglas-fir increased as size class increased in northern Idaho: Only 15% of the saplings sampled by Graham were infected, whereas 25 and 39% of the small and large poles, respectively, were infected.³ Hawksworth (1961) reported that 19% of the ponderosa pines in the 2.54-cm-diameter class were infected in stands infested by southwestern dwarf mistletoe in northern Arizona, but infection increased to 57% in the 12.7-cm-diameter class. Childs (1963), working in the Pacific Northwest, found that uninfected ponderosa pines averaged 1.5 and 1.1 m in

height in lightly and heavily mistletoe-infested stands, respectively, and infected pines averaged 2.3 and 2.0 m in the same stands. Scharpf (1969) reported that only 7% of true firs under 0.9 m tall were infected in severely infested stands in California but that infection intensified rapidly in taller regeneration. The results of infection of Douglas-firs by height classes reported here indicate that little infection can be expected until the trees reach heights greater than 1.4 m in the Southwest.

Because these findings have important implications in managing dwarf mistletoe-infested stands, similar studies should be conducted for other dwarf mistletoe–host combinations in other regions of the western United States. The results show that the generally accepted recommendation that infected overstory pines and true firs be removed before the young stand is 10 years old or 0.9 m tall is more restrictive than need be for Douglas-fir in the Southwest, where little infection occurred in stands under 20 years old or less than 1.4 m tall.

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³Graham did not specify the diameters of the size classes he used.

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Received 31 January 1989

Accepted 16 January 1990